Internal Circulation in Tidal Channels and Straits and Associated AASERT Internal Circulation in Tidal Channels and Straits: a Comparison of Observed and Numerical Turbulence Estimates

David A. Jay
Center for Coastal and Land-Margin Research
Department of Environmental Science and Engineering, Oregon Graduate Institute
Portland, OR 97291-1000
Phone: 1-503-690-1372 Fax: 1-503-690-1273 e-mail: djay@ccalmr.ogi.edu
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LONG-TERM GOAL

The principal long-term objectives of this project and its associated AASERT are to provide:

- a 3-D conceptual understanding of circulation and scalar transport in the numerous estuaries and straits worldwide with both strong tides and buoyancy forcing,
- new modeling tools for this purpose,
- improved analysis methods for defining the non-stationary and non-linear processes that drive circulation in these environments, and
- in concert with related projects, an improved understanding of and numerical modeling capability for vertical turbulent mixing processes in stratified flow.

SCIENTIFIC OBJECTIVES

Present work focuses on the 3-D distribution of the along-channel circulation, hydraulic control and mixing at the estuary entrance, and near-bed and interfacial mixing processes in stratified environments. Specific objectives include:

- test a 3-D mixed analytical/numerical circulation model for sub-areas of the Columbia River estuary, to calculate tidal and residual flow during periods for which data are available;
- examine hydraulic control effects near the mouth of the Columbia River using a three-layer model that includes mixing between layers and bed dissipation;
- analyze near-bed and interfacial turbulent momentum, salt and sediment flux data to better understand vertical fluxes of momentum, salt and sediment in stratified environments;
- develop and disseminate to the oceanographic community wavelet transform tidal analysis and turbulence estimation tools; and
- use wavelet and other tools to analyze key data sets.

APPROACH

This project has taken a unified approach to analyzing the effects of buoyancy on estuarine and shelf tides and scalar transport, as funded by the Coastal Dynamics Program of ONR and the Na-

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tional Science Foundation (NSF) Land-Margin Ecosystem Research (LMER) Program. In all environments of interest, a time-varying density field leads to markedly unsteady tidal flow, which in turn feeds back onto the density field through tidal straining. Scalar transport then depends on the detailed correlations of time-dependent velocity and scalar fields and on vertical turbulent mixing. On a functional level, these efforts have been augmented over the last year by the Oceanographic and Environmental Characterization of Coastal Regions (OECCR), also funded by ONR. OECCR through its network of real-time instrumentation, data analysis efforts and developing modeling capabilities (forming together the CORIE nowcast-forecast system) is providing a wealth of data and numerical modeling results that require interpretation and understanding. The related AASERT project will assist in comparisons of models and data. The understanding that is being developed through the tidal channels project can be transferred to other environments world-wide, just as can the OECCR modeling and forecast methodologies.

WORK COMPLETED

1. We have analyzed data from key periods for which sufficient mean flow (and in some cases, turbulence) data exist to provide detailed information in support of simulations (group).

2. Estimates of key terms in the TKE balance for near-bed and interfacial locations have been made for most stages of the tide at mid-estuary locations. Methods have been developed to remove platform motion and discriminate between internal wave and turbulent variance. This has allowed calculations of TKE, stress components, dissipation and buoyancy flux (D. J. Kay).

3. The evolving semi-analytical model of estuarine circulation has been readied to allow thorough testing against the above data sets. These tests are in progress; (J. D. Musiak and D. A. Jay).

4. A three-layer, laterally averaged model with mixing and bedstress has been assembled and tested through joint ONR and LMER support. It is a generalization of an earlier two-layer model of Helfrich (1995) and is being used to examine hydraulic control, mixing and circulation at the estuary entrance (C. N. Cudaback).

5. Development of continuous wavelet transform (CWT) analyses has been extended to include routines for multiple level, two-component {u,v} rotary analyses (for ADCP current records), and to allow inclusion of subtidal and tidal frequencies. Wavelet cross-spectra analyses and methods for unevenly spaced data are in progress (D. A. Jay).

6. We have conclusively demonstrated the existence of multiple internal tide generation mechanisms in the Columbia River plume area. In addition to the usual shelf-break mechanism, internal tides strongly coupled with the barotropic tide emanate from the estuary mouth (D. A. Jay).

RESULTS

Deciphering estuarine dynamics in the time and frequency domains Sample results derived using CWT and traditional methods are provided here to illustrate the utility CWT methods and the of results of collaboration with LMER. Nearly complete time series of ADCP velocity, water properties, optical backscatter (OBS), near-bed bacterial productivity and zooplankton counts at three levels were obtained in the estuarine turbidity maximum (ETM) reach of the Columbia for 10-19

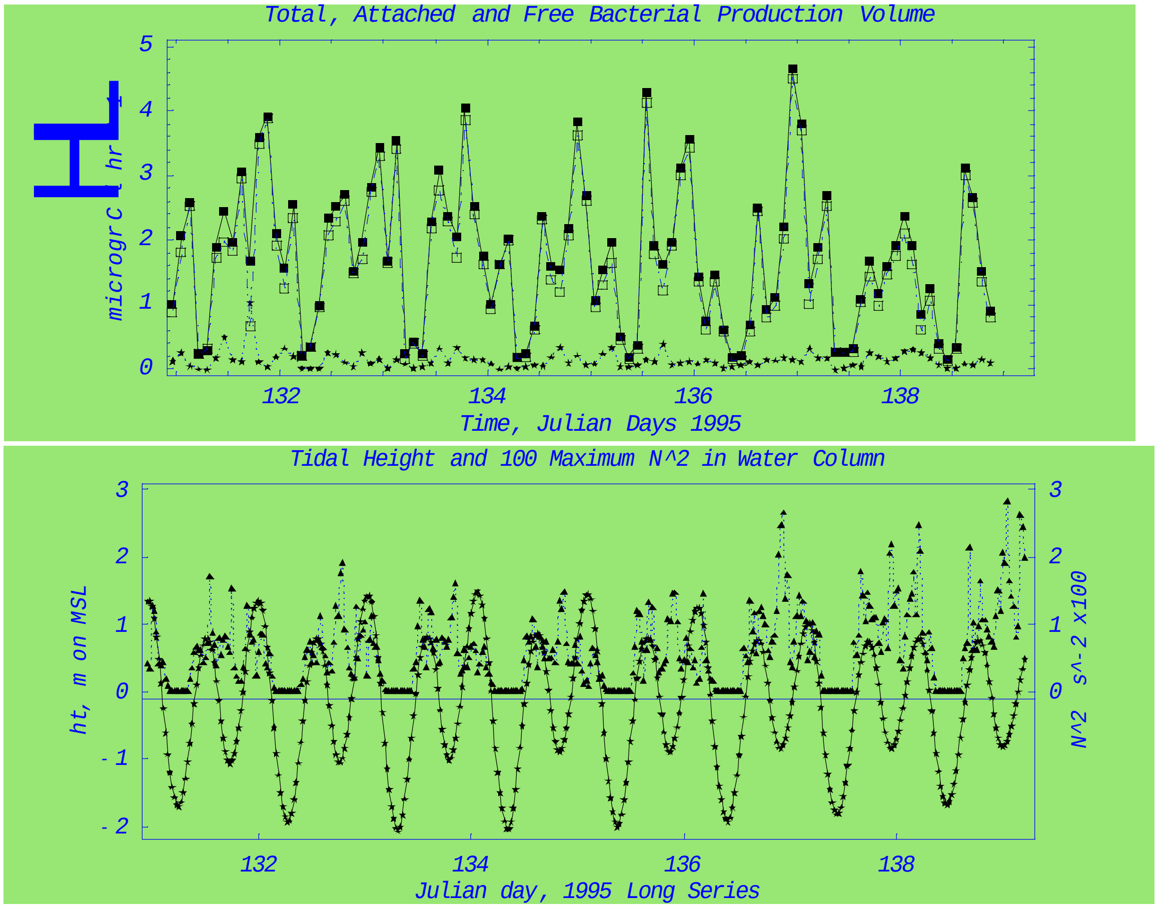

Figure 1: Above - free (⍂), particle attached (③), and total(②) near-bed ETM microbial productivity (the latter two are essentially the same, because free productivity is small). Below -100 maximum N^2 (⇩), which shows the same three high, one low pattern as attached bacterial productivity, and tidal elevation (⍂).

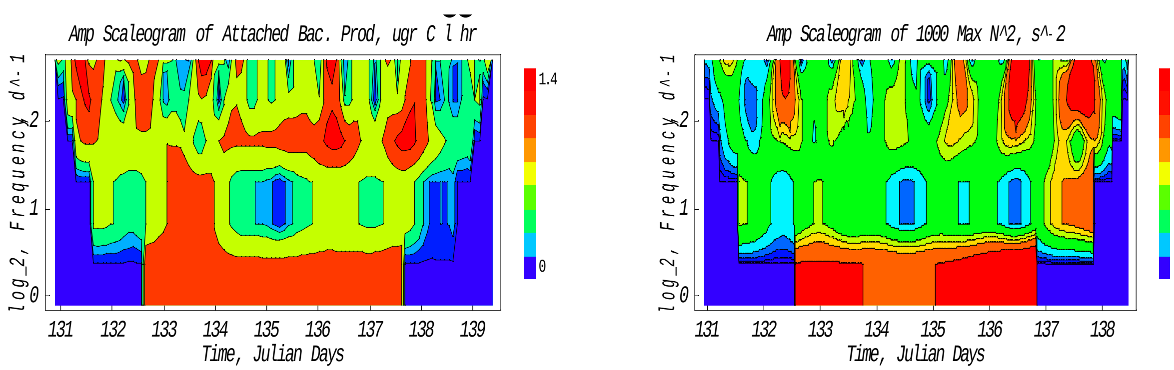

Figure 2: Very similar frequency domain signatures are seen for particle attached bacteria (left) and maximum N^2. Both show strong D_1 (diurnal) and D_3 (terdiurnal) variability because of their temporal pattern of 3 highs and one low per day. No other parameters examined showed patterns of this sort, suggesting the need to determine the actual mechanisms connecting the two variables.

May 1995, during a spring freshet. Shown here are maximum stability N^2, its relationship to the surface tide, and the response of particle-attached bacterial productivity to physical forcing (Figs. 1 and 2). The location of maximum N^2 moves up and down tidally as salt is carried in and out of the system, and $N^2 = 0$ for ~ 6 hrs on greater ebb. Periods of high N^2 occur during each flood and on lesser ebb, as the salt water layer thins, giving a striking pattern of three highs and one minimum per day in maximum N^2. This periodicity is mirrored in a striking way in attached bacterial

productivity (Fig 2). While correlation does not prove causality, an association between N^2 and microbial productivity is logical (particles are disrupted by shear) and has spurred a search for a definite mechanism.

Self-consistent, optimal analyses of tidal and subtidal variance: Development of new tidal analysis methods based on CWTs encourages a rethinking of the relationship of tidal and non-tidal processes. Historically, analysis of tides has been isolated from the oceanographic mainstream, and other oceanographers have usually started their analyses with low-passed records from which tides were excluded. In fact, the non-linear transformation used in least-squares harmonic analysis sometimes gives very different results from a linear convolution analysis (e.g., a CWT or complex de-modulation). Obviously, it is essential to apply one method to the entire tidal and subtidal spectrum, if one wants to understand the relationship of tidal and subtidal processes.

Analyses of turbulent processes: These are vital to Tidal Channels modeling, for development of a qualitative understanding of estuarine scalar transport, and for improvement of numerical turbulence algorithms. Acoustic Doppler velocimeter (ADV) technology provides impressive capabilities and can be used in a variety of ways, provided one is aware of its strengths and weaknesses (Voulgaris and Trowbridge, 1997). We are looking at major terms in the turbulent kinetic energy (TKE) budget and their variations with time and governing parameters like the gradient Richardson number Ri_g as part of D. J. Kay's thesis.

Hydraulic control at the estuary mouth: Two-layer hydraulic control theory exhibits many features of estuarine circulation, but cannot reproduce the pronounced flood interfacial jet and ebb expansion of the interfacial layer to encompass most or all of the flow. A three layer model has been developed that generalizes on the two-layer model of Helfrich (1995) by including bed friction, an explicit interface layer and turbulent entrainment between layers (via the Ellison and Turner, 1959 formulation). Although such a model cannot reproduce all features of circulation at the estuary mouth (e.g., different interfacial thickness in the velocity and salinity field), preliminary results are very encouraging (Figure 3).

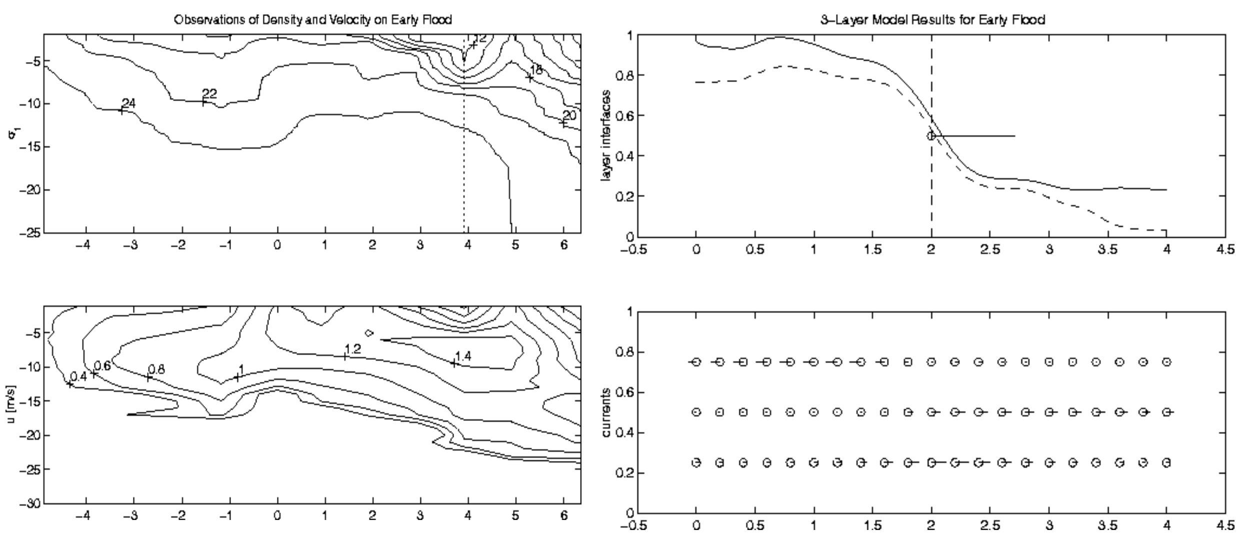

Figure 3. Left: Observations of flood CTD density (above) and ADCP along-channel velocity (below) at the primary entrance constriction (dotted vertical line); the interface thins and accelerates at the constriction. Right: three-layer model results for a similar bathymetry (without channel curvature). The interfacial layer is too thin, buts shows a qualitatively correct thinning and acceleration at the constriction.

Impacts/Applications

1. The CWT analysis methods devised in this project should be widely applicable to analyses of non-stationary tidal phenomena and also to the problem of optimal extraction of frequencies from a short record. Together, these circumstances constitute a large percentage of all applications of tidal analysis. CWTs can also provide a consistent analysis of tidal and subtidal variance very difficult to carry out with harmonic analysis.

2. Understanding optical and acoustic properties in the littoral requires a unified approach to physical and ecosystem dynamics, because littoral ecosystems are so strongly forced by advection and mixing. In this regard, the collaborative approach of the Tidal Channels project with other research funded by ONR and the National Science Foundation can serve as a good model.

3. The three-layer internal hydraulics model and the more general semi-analytical 3-D modeling approach being developed under this project should be widely applicable to other estuaries and should materially improve our understanding of estuarine circulation.

4. The analyses of major terms in the TKE balance and their comparisons to numerical estimates (under AASERT funding) should provide an improvement in qualitative understanding of turbulent mixing processes, as well as inproving numerical model procedures.

Transitions

Two CWT tidal analysis programs with sample data sets illustrating their use have been placed on the PI's web page (see CWT software library sub-heading under http://www.ccalmr.ogi.edu/~djay). Dr. R. Signell of the US Geological Survey has set up a link to these programs on his Sea-Mat web site (http://crusty.er.usgs.gov/sea-mat), to make the programs more widely available to the research community.

Related Projects

Work for the tidal channels project has been coordinated with the National Science Foundation Columbia River Land-Margin Ecosystem Research (LMER) Program and with the Oceanographic and Environmental Characterization of Coastal Regions (OECCR) funded by ONR.

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